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Article

Influence of high-frequency radiation on turbulence measurements on a 200 m tower

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Abstract

Turbulence measurements conducted by means of Solent Gill ultrasonic anemometers at several altitudes on the 200 m tower at the Research Center Karlsruhe showed white noise behaviour at the high-frequency end of the spectra with increasing measurement height. In a number of data sets with a time resolution of 48 ms, the computed power spectra of the velocity components and temperature converge into white noise and the decline in the inertial subrange expected theoretically is hidden. The noise covers a broad range of the spectrum, which greatly increases variance and makes further data analysis difficult. The cause of this parasitic noise is found in high-frequency radiation from regional longwave transmitters in the frequency range of 150 to 200 kHz, which interferes with the transducer crystals. The resonance frequency of the transducer crystals is 180 kHz. It is found that a thin, grounded mesh wire around the sensor head acts like a Faradays cage, protecting the transducers from the radiation. Negative side effects, like eddy production from the cage or a modified mean wind speed can be excluded from results gained by different ultrasonic anemometers, operated simultaneously close to the ground. The mesh wire shield thus is a permanent solution to these problems in case of longwave transmitters surrounding the measurement site.

Zusammenfassung

Turbulenzmessungen in mehreren Höhen mit Solent Gill Ultraschallanemometern am 200 m hohen Mast des Forschungszentrums Karlsruhe zeigten in den berechneten Turbulenzspektren am hochfrequenten Ende ungewöhnlich hohe Spektraldichten, die einem Weißen Rauschen zuzuordnen sind. In zahlreichen Datensätzen mit einer zeitlichen Auflösung von 48 m s gehen die berechneten Spektren der Geschwindigkeitskomponenten und der Temperatur in ein Weißes Rauschen über, dessen Niveau mit der Höhe zunimmt. Der theoretisch erwartete Rückgang im Inertialbereich wird durch das starke Rauschen überdeckt. Das Rauschen umfasst einen großen Bereich des Spektrums, so dass die Varianz zum Teil beträchtlich ansteigt, was eine weitere Datenauswertung schwierig macht. Die Ursache des störenden Rauschens sind Hochfrequenz-Einstrahlungen eines regionalen Langwellensenders, die in einem Frequenzbereich zwischen 150 und 200 kHz liegen und mit den Quarzkristallen der Schallwandler interferieren. Die Resonanzfrequenz der Kristalle liegt bei 180 kHz. Mit Hilfe eines dünnen, geerdeten Drahtgitters um den Gerätekopf wird ein Faradayscher Käfig konstruiert, der die Schallwandler gegen die Einstrahlungen abschirmt. Negative Effekte, wie z. B. Wirbelablösung am Gitter oder Veränderung der mittleren Windgeschwindigkeit, können nach einem Vergleich dreier simultan betriebener Ultraschallanemometer in geringem Abstand zueinander ausgeschlossen werden, so dass das Gitter eine permanente Lösung im Fall von Störungen durch Langwellensender nahe des Messgeländes ist.

1 Observation of white noise

With the rapid progress in the development of ultrasonic anemometers during the past decades, the eddy-correlation method has become a standard for measuring turbulent flows in the atmospheric boundary layer. Since 1997, turbulence measurements have been carried out by means of Solent Gill ultrasonic anemometers (type R2, 20.83 Hz) at altitudes of 4, 40, 100 and 200 m on the 200 m meteorological tower at the Research Center Karlsruhe. Further informations about the instrumentation of the tower are given by Kalthoff and Vogel (1992).

It was detected that the spectra unexpectably showed a white noise spectrum at the high-frequency end. Consequently, the expected –5/3-slope in the inertial subrange cannot be observed. Fig. 1 shows two examples of time series and power spectra $S_u(f)$ respectively ($\overline{v}=0$) with white noise and without the noise (the technique how to remove the noise is described below). In case (a.), the expected slope in the inertial subrange only ranges up to a frequency of 0.2 Hz, from this point onward the spectrum converges into white noise covering the entire high-frequency end. Compared to case (b.) under similar meteorological conditions, these random fluctuations

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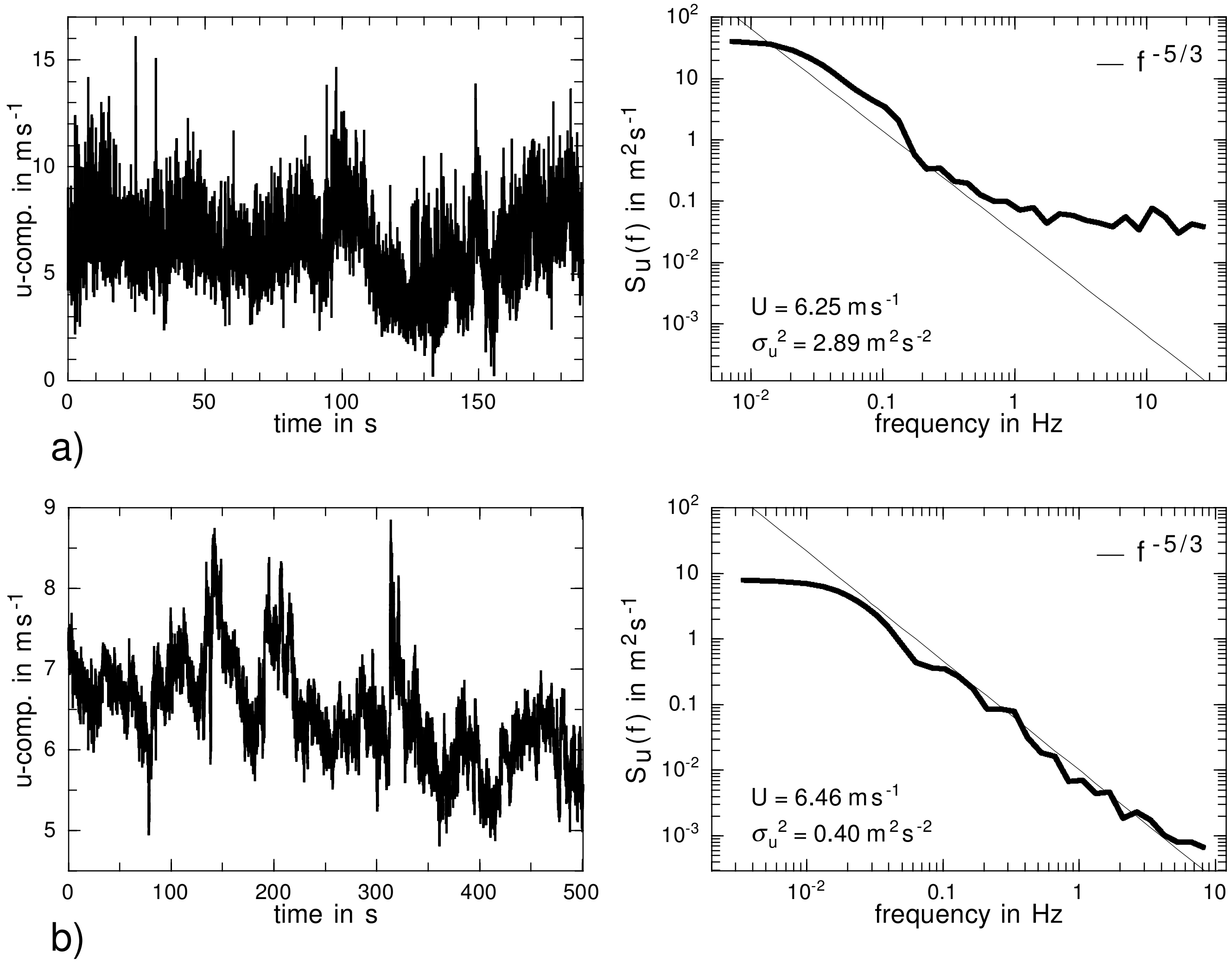

Figure 1: Time series and power spectra in 200 m. a) Measured on 20 October 1999 with white noise; b) measured on 22 May 2000 without noise.

increase the variance to 2.89 m^2s^{-2}, while mean wind speed and wind direction are nearly not affected, as obvious from comparisons with cup anemometer and wind vane of the same height. The relatively high mean wind speed of $U = 6.25$ m s^{-1} guarantees that this noise is not caused under weak turbulence conditions from electric noise of the data acquisition system or by inaccurate data handling. Aliasing can be excluded as that effect would only lead to a slight energy gain at the very high end of the spectrum. Compared to (b.), the noisy data cannot be used for any further scientific computation purposes.

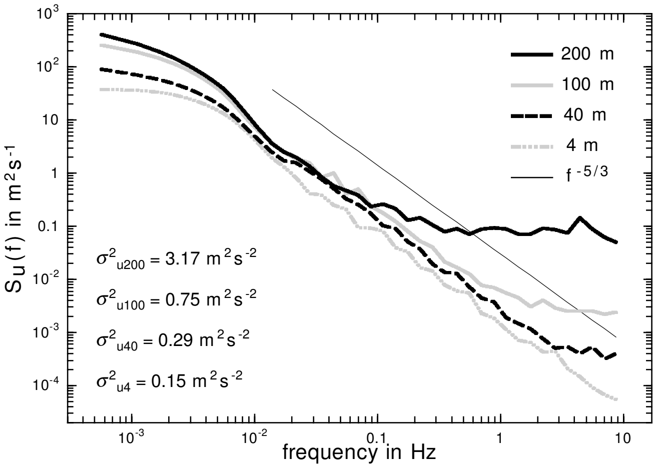

Figure 2: Power spectra from all observation heights.

It was further found that the noise is not present at lower levels closer to the ground and increases with altitude to the maximum level of the 200 m tower in all three velocity components (Fig. 2) and in the temperature signal. There are no specific wind directions or wind speeds or temperature profiles where this effect is present or absent.

Besides of potential deviations from the theoretical assumptions, there are a number of factors possible determining the quality of eddy correlation methods. Several investigations were performed during the last years to specify the influence of the transducers, the supporting arms (e.g. Grelle and Lindroth, 1994; Foken and Wichura, 1996; Vogt et al., 1997; Miller et al., 1999; Wieser et al., 2001) or the meteorological tower (Lenschow, 1986; Barthlott and Fiedler, 2003) on the turbulence spectrum and data quality. However, none of these mentioned error sources could be used to explain the unusual results of the turbulence spectra gained from the measurements with the Gill ultrasonic anemometer. Consequently, a number of tests have been carried out in order to locate the cause.

2 Error diagnostics

The Gill anemometer can be operated in four measuring modes, which differ in the readout frequency (21 Hz or 56 Hz) and in applying software for correction of the shading effect (GILL-INSTRUMENTS-LIMITED, 1990). First, all four modes during the measurement have been applied in order to exclude possible errors in data processing, but this produced no findings. Interference along the 200 m cable could also be excluded by collecting the data straight from a laptop computer on top of the mast in the direct vicinity of the ultrasonic anemometer. Oscillations of the tower booms or of the tower itself could be excluded, since such oscillations would show only a single secondary peak, and not a uniformly distributed white noise level. Also the use of an other type of ultrasonic anemometer (Kaijo-Denki) at the same height of 200 m did not show the effect of the Gill anemometer. A special hint was found from the installation of the ultrasonic anemometer on a much shorter boom approximately 0.3 m long. In this configuration, the noise was much weaker and disappeared completely when the ultrasonic device was kept inside the tower. The open lattice structure of the tower acts like a Faradays cage, isolating the anemometer from electromagnetic radiation.

Using an Anritsu Spectrum Analyzer (MS2601B: 9 kHz–2.2 GHz), the high-frequency radiation inside and outside the tower was measured by means of an antenna. Compared to the situation inside the tower, the test from the outside revealed signals in the frequency range of 150 kHz to 200 kHz. This proved the existence of high-frequency radiation and demonstrated that the ultrasonic anemometer is affected by this radiation, as the noise disappeared in the data inside the tower. In a next test, it was shown that the sonic anemometer could be isolated from this radiation, resulting in a strong decrease of the noise overlay. For this reason, a grounded mesh wire shield was installed around the head of the ultrasonic device (Fig. 3). Fig. 4 shows two measurements conducted consecutively with and without the mesh wire shield. The data measured with the mesh wire in place reveal no white noise, and variance is reduced from 26.78 to 1.59 m^2s^{-2}. In a different test, the mesh wire was only put around the electronics in the sensor base, but the data still revealed white noise.

Returning to Fig. 1, we note that this is just another example of the effect demonstrated in Fig. 4. Each data set has been taken under similar meteorological conditions but at different times.

Figure 3: Gill ultrasonic anemometer with mesh wire.

3 Origin of white noise

The tests show that high-frequency radiation is present in the surroundings of the Karlsruhe tower. The frequencies are between 150 and 200 kHz (wavelength from 2 to 1.5 km) and were confirmed by a spectrum analyzer. It is known from the manufacturer that the R2 unit may be sensitive to interference in the frequency range of 150 to 200 kHz (WALSH, Gill Instruments Limited, 2002, personal communication). This radiated frequency interferes with the resonance frequency of the anemometer transducer crystals. Electromagnetic energy might be coupled into the system through the connecting wires between the transducer crystals and the measurement electronics (electromagnetic interference). These crystals control the digital counter, which measures the time required for a sonic pulse to move from one transducer to the other. The time of flight calculations are now modified by the affected transducer crystals. As a result, random-like deviations of the true time occur at all wind speeds and directions (WALSH, Gill Instruments Limited, 2002, personal communication). These

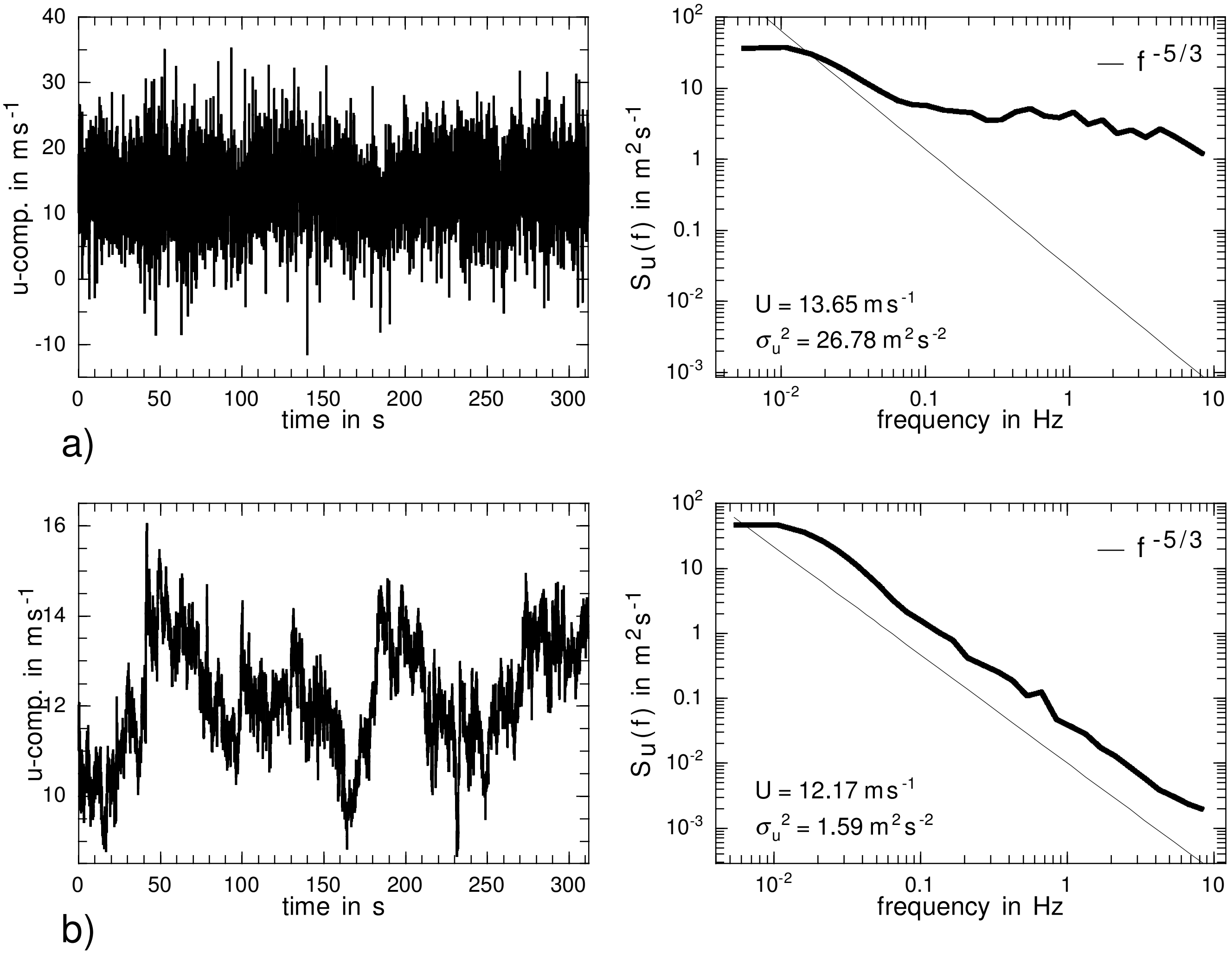

Figure 4: Time series and power spectra in 200 m, measured on 7 December 1999. a) Without mesh wire; b) with mesh wire.

random-like deviations of the time of flight calculations lead to a white noise which can only be detected in the high-frequent end of the spectrum, since the variance in the low-frequent part is too high. The frequency range of concern is occupied by long-wave broadcasting and is present almost all over the world; hence, there is no possibility to turn off this radiation. A permanent mesh wire shield around the sensor head therefore is an effective way to avoid white noise in the turbulence data.

4 Influence of the mesh wire on the data quality

In measurements of atmospheric turbulence, perturbations of the flow caused by a sensor introduced into the wind field must be minimized. A mesh wire around the sensor head certainly must be handled with care. In the presence of a transmitter at this frequency, however, there is no other way of obtaining good data with the Gill anemometers. As the wire diameter is very small (1 mm), also deviations should be kept to a minimum. Nevertheless, a further test was made to determine whether the mesh wire affects the data in a negative way. Three 4 m masts have been installed for collecting turbulence data during several days in summer 2000. The distance between the masts was 2 m. One ultrasonic anemometer had a mesh wire over the sensor head (mast 1), the other two anemometers were operated normally (masts 2 and 3). As no noise from broadcasting stations can be observed at the ground, data obtained from such an installation can be used to determine potential side effects due to the mesh wire.

The observed percentage differences in the mean *u*-components of the wind and the differences in the variances of *u* and *v* between mast 1 and masts 2 or 3 are given in Tab. 1. It can be seen that the differences between the case with the mesh wire and mast 2 are of the same order of magnitude as the differences between the two masts without a mesh wire. Also in the spectral distribution of energy there are no notable differences. As eight measuring cycles of 6 ms are averaged in mode 1, the eddies generated through wake production by the mesh wire with a diameter of 1 mm are too small to affect data quality in a larger way. From these observations, it is possible to conclude that the mesh wire has no negative impacts on the turbulence measurements in this mode.

Table 1: Differences of mean and turbulent quantities.

	Mast 1-2	Mast 2-3
$\overline{u}$	+ 4 %	+ 6 %
$\overline{u'^2}$	+15 %	+13 %
$\overline{v'^2}$	+16 %	+15 %

5 Conclusions

Even sophisticated meteorological measurement techniques may be confronted with unexpected sources of error, such as high-frequency radiation from a local transmitter. This kind of problem can occur on other meteorological towers as well and also may cause problems when a Gill-type anemometer is used. The later model (R3 unit) has improved signal processing capabilities in locating the correct transducer crystal receive pulse. However, as the same type of transducer crystal is employed, it would be impossible to be certain that this unit would not behave in the same way. A better shielded sensor head would be helpful, in order to prevent similar problems from occurring in the future.

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